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(71) Applicant: International Business Machines
Corporation
Old Orchard Road
Armonk, N.Y. 10504(US)

(72) Inventor: Chevillat, Pierre René
Im Baumgarten 12
CH-8802 Kilchberg(CH)
Inventor: Eleftheriou, Evangelos

Abendweg 3
CH-8038 Zuerich(CH)
Inventor: Maiwald, Dietrich G.U.
Neugutstrasse 3
CH-8820 W&ae.Denswilwil(CH)
Inventor: Quintin, Michel
244 Chemin de l'Adret
F-06610 La Gaude(FR)

(74) Representative: Bonneau, Gérard
Compagnie IBM France Département de
Propriété Industrielle
F-06610 La Gaude(FR)

(54) Process of synchronizing a receiving modem after a training on data.

(57) In a data transmission wherein a transmitting modem transmits data signals to a receiving modem via a telephone line, the process of the invention consists in rotating (12), in the transmitting modem, the phase of the point of the constellation resulting from a group of data bits by a predetermined phase value, and then rotating (22) after, a predetermined

delay in the receiving modem, the phase of the estimated point resulting from the transformation of the analog signal, by the opposite of said predetermined phase value, the mean-square error between the rotated point and the estimated point of the constellation being used to determine whether the receiving modem is out of synchronization or not.

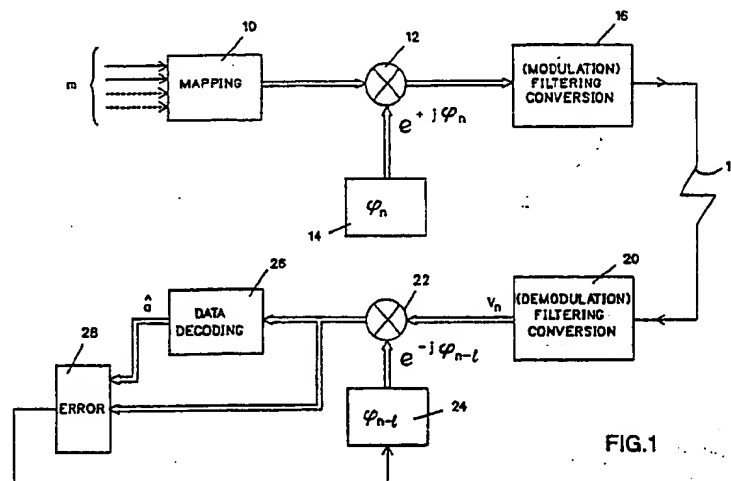


FIG.1

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PROCESS OF SYNCHRONIZING A RECEIVING MODEM AFTER A TRAINING ON DATA

The present invention relates to data transmission systems wherein a transmitting modem transmits data signals to a receiving modem via a telephone line, and particularly to a process of synchronizing the receiving modem with respect to the transmitting modem after a training on data.

In the transmission of data between a first data terminal equipment (DTE) and a second DTE over telephone lines, each DTE is equipped with a modem wherein the carrier signal is modulated by the data in a modulator at the sending end and demodulated in a demodulator at the receiving end. Where the transmission takes place between a plurality of local DTEs and a plurality of remote DTEs, a multiplexer enables a single modem to be connected to the plurality of DTEs that receive or transmit data on a time-multiplex basis. That is, each data byte sent to or received from the local DTE is formed by juxtaposing groups of bits received from or sent to each remote DTE, with the number of bits in each group being dependent on the transmission speed assigned to the corresponding DTE.

The data bit stream received at the input of the modem is loaded in a serializer/deserializer which provides parallel groups of bits, the number of bits in each group depending on the data bit rate of the modem. Each group is converted to a point in a phase-amplitude diagram, all the points of the diagram forming a constellation. Each point is then translated into a couple of values corresponding to the coordinates of the point. The technique for coding the points of the constellation is described in the article entitled "Multidimensional Signal Constellations for Voice-band Data Transmission" by A. Gersho and V. Law rence, published in IEEE Journal of Selected Area in Communications, vol. SAC-2, No. 5, 1984.

Then, these two quadrature signal values are modulated by a carrier signal before being spectrally shaped in a filter centered at the carrier frequency providing as an output a number of samples of the shaped signal each baud time, complying with the sampling theorem. At last, the samples are provided to the digital-to-analog converter in order to be converted into an analog signal to be sent over the telephone line.

Reciprocally, on the other direction, the analog signal received from the telephone line is first converted into digital samples. The samples are filtered, and the output of the filter representing two in-phase and quadrature components, are used to provide a point in the plane corresponding to a group of bits. The juxtaposed groups of bits are then serially transmitted to the DTE or distributed

to the different DTEs in case of multiplexing.

When a transmission of data is initiated from a local modem to a remote modem, a training sequence is sent to adjust the control gain, the equalizer coefficients and all similar coefficients of the remote modem. There is no problem for the remote modem to identify the beginning of the data message which follows the training sequence since the end of the training sequence is recognized by the remote modem receiver. But, in some cases, the remote modem receiver has to adjust itself on the data received from the local modem. This happens in a multipoint configuration where one remote tributary modem which has been disconnected from the network has to be connected again. In such a case, the training of this tributary modem is made by using data, well-known as "training on data", with the difficulty to recognize the beginning of the data message.

In most cases, the difficulty for the receiving modem to synchronize in case of "training on data", is not detrimental since only some data bits are lost, and it is sufficient to retry the data transmission after the synchronization has been made.

But, there are modem configurations wherein the loss of synchronization after a "training of data" is very detrimental. Thus, due to the compliance with the CCITT recommendations, the today modems use a modulation rate of 2400 bauds resulting in data bit rates which are multiple of 2400 such as 2400, 4800, 9600, 14400 bps. However, with a high data bit rate such as 19 200 bps, keeping a modulation rate of 2400 bauds leads to a constellation which is too complex to be easily processed. The solution would be to widen the bandwidth. Unfortunately, the available telephone line bandwidth is limited to about 3000 Hz, which means that only a bandwidth of a maximum of about 2900 Hz is possible if a good performance transmission without line distortions is required. Therefore, and in order to have a higher integration, the solution which has been described in European patent application 89480004.4 has been to keep the same external hardware and to modify the signal processor software in order to increase the modulation rate. In such a modem, the signal received from the line is processed in such a way that the signal processor provides groups of 7 bits at a modulation rate of 2743 bauds. 8 groups of 7 bits are then converted into 7 words of 8 bits which are serialized in order to be transmitted to the DTE in the form of a serial stream at 19 200 bits/s. Such an adapted modem behaves as a modem operating at a modulation rate of 2743 bauds on a periodic process interval of 8/2743 s. corresponding to

which determines the point of the constellation which is estimated to correspond to the point of the constellation which has been originally transmitted. The estimate \hat{a} and the phase rotated signal are used as inputs in the error circuit 28 which computes the mean-square error in order to minimize the expression

$$\sum_{n=0}^N |V_n e^{-j\phi_{n-l}} - \hat{a}|^2.$$

over a number of baud times.

If the above expression is sufficiently important, proving that the receiving modem is out of synchronization because the time delay has changed, the phase sequence provided by sequence block 24 is advanced (or delayed) in order to subsequently minimize the error (there is a minimum error due to noise). It should be noted that, in addition, correct equalizer updating requires to multiply the decision error by $e^{+j\phi_{n-l}}$ before applying it in the update algorithm.

Ideally, the phase sequence should be designed such that signal decoding is incorrect in all other shift positions of the sequence. This generates a large mean-squared error whenever the transmitting modem sequence and the receiving modem sequence are not synchronized.

The choice of the phase sequence depends upon the constellation which is used. Indeed, by definition the error is zero if the constellation is correctly positioned i.e. for phase = 0° . But the error is also zero for a phase rotation wherein the constellation is correctly positioned, that is when the constellation presents a rotational symmetry. Therefore, the constellation-dependent properties have to be taken into account when designing a phase sequence which maximizes error accumulation during loss of synchronization.

In fact, there exists two types of constellations, the constellations having a rotational symmetry of 90° (and the multiple 180° , 270°) such as the 16-point constellation shown on Figure 2a, or the 128-point constellation shown on Figure 2b. With modems using such constellations, the phase sequence must be chosen so that there is no possibility of dephasing the signal of 90° , 180° or 270° in case of loss of synchronization by the receiving modems. In other words, the difference between a phase value of the sequence and any other value of the same sequence, should not be 90° , 180° , 270° or 360° .

Another category of constellations are those having only a rotational symmetry of 180° , such as the 144-point constellation shown on Figure 2c or the 256-point constellation shown on Figure 2d. With modems using such constellations, the phase

sequence should be chosen such that the difference between a phase value of the sequence and any other phase value of the same sequence be never 180° or 360° .

For sake of example of the implementation of the invention, modems operating at a speed of 19 200 bits/s are now considered. Such modems operate according to the trellis-coded modulation (TCM) technique with a modulation rate of 2743 bauds, and use a constellation of 256 points as shown on Figure 2d. It must be noted that the same constellation could be used in modems operating at a speed of 19 200 bits/s, but which do not operate in TCM, and with a modulation rate of 2400 bauds.

Figure 3 represents the mean-square error of a receiving modem which applies the 256-point constellation of Figure 2d, with a phase offset to an incoming stream of data signals. As shown, the error is zero if the constellation is correctly positioned for 0° or 360° , but is also zero for 180° . Conversely, the error is maximum for 90° and 270° .

In the above example, a cyclic phase sequence of $k = 8$ values ($\phi_{n+k} = \phi_n$) associated with the multiples of 45° may be selected. The order of the sequence to be applied can be checked by tabulating an 8x8 matrix with the phase sequence in the first row and the seven sequences created by all single circular shifts in the remaining rows. By inspecting each column, the angle differences with respect to the top value yielding 0° and 180° , or 90° and 270° are marked. For a good phase sequence, 0° and 180° should not appear in any row of the shifted sequences, or in case they occur, their minimal error contributions must be compensated within the same row by an equal number of 90° or 270° difference. Thus, the sequence :

$\phi_n = \{ 0^\circ, 135^\circ, 225^\circ, 90^\circ, 270^\circ, 45^\circ, 315^\circ, 180^\circ \}$

was found to meet the above criteria.

Another cyclic phase sequence with favorable error-accumulation properties is derived from 36-phase modulation, where all phase values are multiples of 10° .

But other phase sequences with k being either less than 8 or more than 8, and a phase unit other than 45° or 10° can be used. Thus, cyclic a sequence of 9 phase values, derived from a 20-phase scheme (all value are multiples of 18°) can be considered.

Though all the above examples consider cyclic phase sequences, it must be noted that the invention is not limited to cyclic sequences. Cyclic sequences are only easier to implement than non-cyclic sequences.

In summary, the invention can be implemented

a block of 56 bits which is transmitted to the DTE.

Assuming now that the above modem be connected, not to a single DTE, but to several DTEs (the so-called multiplex configuration), a loss of synchronization in data results in an important drawback. As a matter of fact, multiplexing data between several DTEs means that, each baud time, some bits are sent to a first DTE, some other bits are sent to a second DTE, and so on. If a loss of synchronization happens, which means that the determination of the beginning of a baud time is erroneous, the bits are not dispatched correctly, and the bits received by each DTE are erroneous.

It is therefore the object of the invention to provide a solution enabling the frame synchronization of the receiving modem to be achieved after a "training on data".

This solution is provided by a process implemented in a data transmission modem wherein a transmitting modem transmits data signals to a receiving modem via a telephone line, the transmitting modem being of the type wherein, at each baud time, a group of bits is translated into a point of a constellation defined by an amplitude and a phase, before the point is being transformed into analog signals transmitted over the telephone line, and the receiving modem being of the type wherein each point resulting from the transformation of analog signals received from the telephone line is estimated as being a point of the constellation before being translated into a group of bits.

The process according to the invention consists in rotating, in the transmitting modem, the phase of the point of the constellation, by a predetermined phase value, and then, in the receiving modem, rotating, after a predetermined delay, the phase of the point resulting from the transformation of analog signals, by the opposite of the predetermined phase value, computing the error between the rotated point and the estimated point of the constellation, and modifying, in response to the error, the predetermined phase value so that the subsequent error be reduced to a minimum compatible with the modem operation.

Another object of the invention is a synchronization system also implemented in the above-mentioned data transmission system, comprising enphasing means in the transmitting modem for adding, at each baud time, a predetermined phase value taken amongst a sequence of phase values, to the phase of the point of the constellation, dephasing means in the receiving modem for subtracting, at each baud time, the predetermined phase value from the phase of the point provided after transformation of the receiving analog signals, error means for determining the mean-square error between the point obtained after the predetermined phase value has been subtracted, and the es-

timated point of the constellation, and control means responsive to the mean-square error for advancing or delaying the sequence of phase values in order to reduce the error to a minimum compatible with the modem operation.

The foregoing and other objects will be more fully understood from the following description in reference to the drawings wherein :

Figure 1 depicts a flow diagram showing a data transmission system incorporating the invention;
Figure 2a shows a graphic of a 16-point constellation;

Figure 2b shows a graphic of a 128-point constellation;

Figure 2c shows a graphic of a 144-point constellation;

Figure 2d shows a graphic of a 256-point constellation; and

Figure 3 is a diagram representing the mean-square error in function of the phase-rotation of the 256-point constellation.

Figure 1 shows a data transmission system wherein a group of m bits is translated, at each baud time, by mapping device 10 into a point of a constellation defined in the complex plane by an amplitude and a phase. The two coordinates of the point define a complex signal (it must be noted that complex signals are represented by a double line whereas real signals are represented by a single line) which is multiplied, in multiplier 12 by the complex value $e^{j\phi_{n-1}}$ (which is equivalent to a phase rotation. ϕ_{n-1} is a phase value of a predetermined sequence provided by phase sequence block 14. Then, the rotated signal is processed by modulation, filtering and conversion block 16 before being transmitted over telephone line 18 to the receiving modem. It should be noted that in block 16, the word modulation is between brackets since the invention can be incorporated also in baseband modems which do not use any modulation.

At the receiving modem, the analog signal is processed by demodulation, filtering and conversion block 20. It results from this processing at each baud time, a point of the complex plane defined by an amplitude and a phase. The resulting complex signal V_n is multiplied, in multiplier 22, by the complex value $e^{-j\phi_{n-1}}$ (which is also equivalent to a phase rotation). ϕ_{n-1} is a phase value of the same predetermined sequence as for the transmitting modem, which is provided by sequence block 24. But, at baud time n , the signal V_n which is processed corresponds in fact to the symbol which has been processed, in the transmitting modem at baud time $n-1$, due to the time delay induced by the transmitting modem processing, the telephone line and the receiving modem processing.

The phase rotated signal issued from multiplier 22 is then decoded in data decoding device 26

in all data transmission systems using modems of the type wherein, at each baud time, a group of bits is translated into a point of a constellation in the transmitting modem, and reciprocally in the receiving modem. But, the invention is more particularly applicable to systems using modems configurations wherein the loss of synchronization after a "training on data" is detrimental. This is the case when the modem is software-adapted for operating at a modulation rate different from the basic rate of the environment, and especially if the data received by the receiving modem have to be multiplexed between several DTEs.

Though the invention has been described in reference to preferred embodiments, it is within the skill of the man of the art to bring changes and details by using the teachings of the description and without departing the scope of the invention.

Claims

1. In a data transmission system wherein a transmitting modem transmits data signals to a receiving modem via a telephone line; said transmitting modem being of the type wherein, at each baud time, a group of bits is translated into a point of a constellation defined by an amplitude and a phase, before said point is being transformed into analog signals transmitted over said telephone line; said receiving modem being of the type wherein each point resulting from the transformation of analog signals received from said telephone line is estimated as being a point of the constellation before being translated into a group of bits; process of synchronizing said receiving modem with respect to said transmitting modem in case of training on data, characterized by the following steps :

in said transmitting modem, rotating the phase of said point of the constellation by a predetermined phase value;

in said receiving modem :

- rotating, after a predetermined delay, the phase of said point resulting from the transformation of analog signals, by the opposite of said predetermined phase value;
- computing the error between said rotated point and said estimated point of the constellation; and
- modifying, in response to said error, said predetermined phase value so that the subsequent error be reduced to a minimum compatible with the modem operation.

2. in a data transmission system wherein a transmitting modem transmits data signals to a receiving modem via a telephone line; said transmitting modem including mapping means for transforming at each baud time a group of data bits into a point of a constellation defined by an amplitude and a

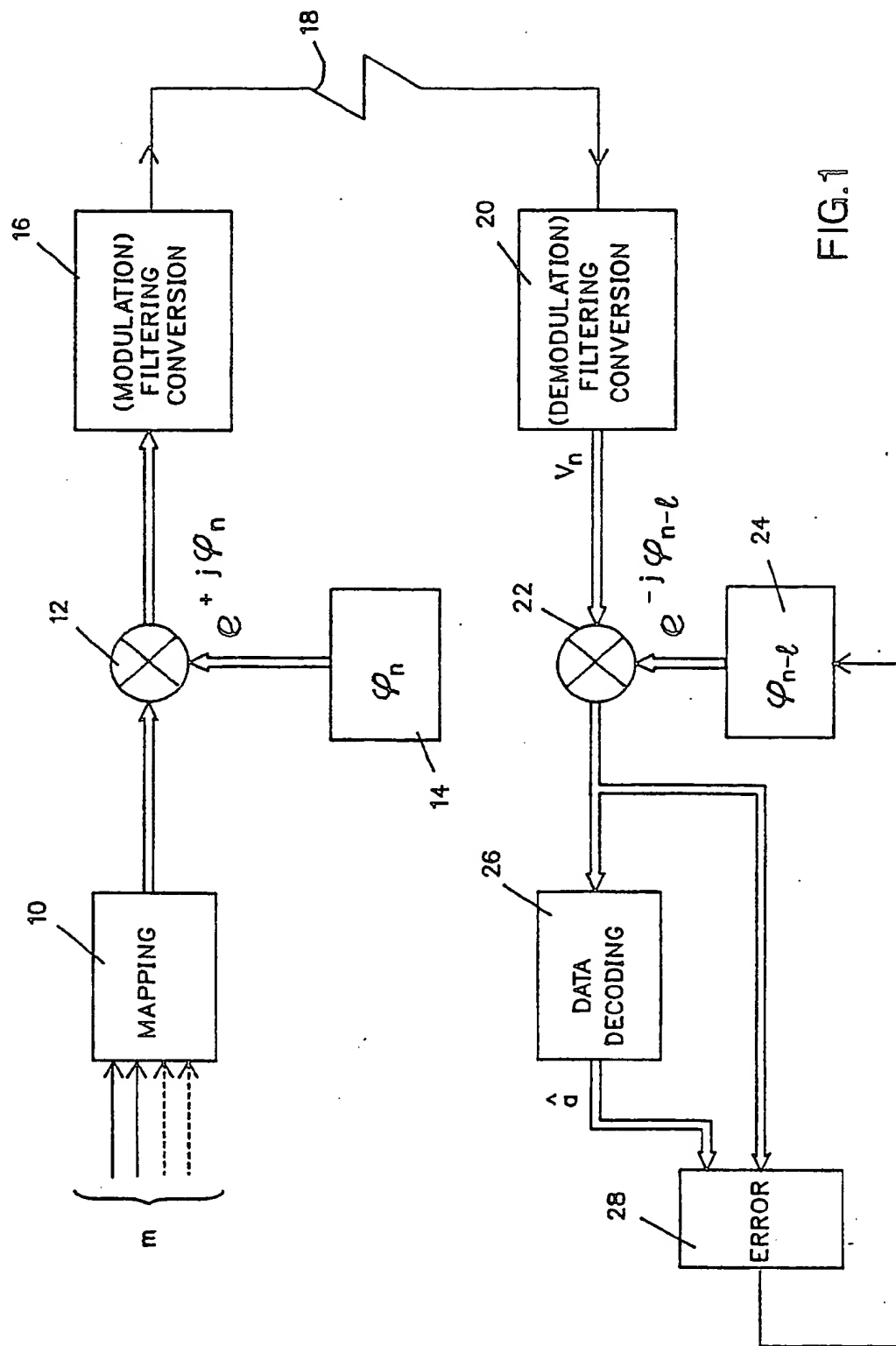
phase in the complex plane, and analog transforming means for transforming the coordinates of said point to analog signals to be transmitted over said telephone line; said receiving modem including digital transforming means, for transforming the analog signals from the telephone line into coordinates of a point defined by an amplitude and a phase in the complex plane, and decoding means for determining an estimated point in the constellation corresponding to the point provided by said digital transforming means; a synchronization system characterized in that it comprises :

enphasing means in said transmitting modem, for adding, at each baud time, a predetermined phase value taken amongst a sequence of phase values, to the phase of said point provided by said mapping means;

dephasing means in said receiving modem for subtracting, at each baud time, said predetermined phase value from the phase of the point provided by said digital transforming means;

error means for determining the mean-square error between the point obtained after said predetermined phase value has been subtracted, and the estimated point of the constellation; and

control means responsive to said mean-square error for advancing or delaying said sequence of phase values in order to reduce said error to a minimum compatible with the modem operation, thereby synchronizing the frames of data received by said receiving modem with respect to the frames of data transmitted by said transmitting modem.



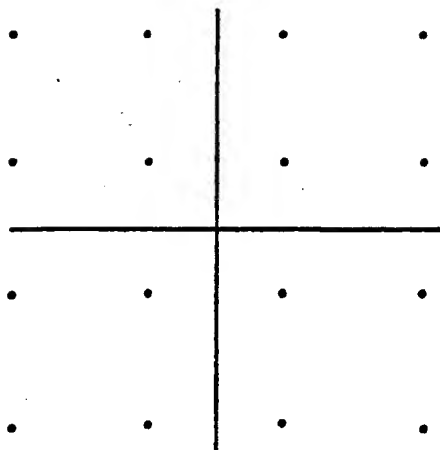


FIG. 2a

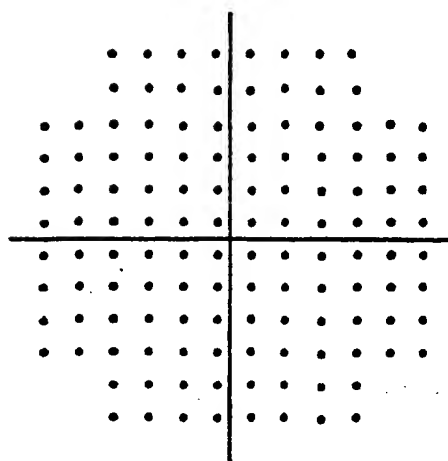


FIG. 2b

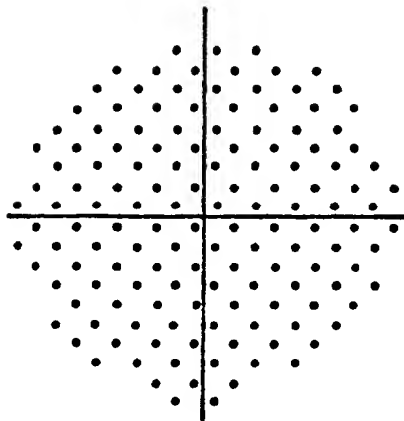


FIG. 2c

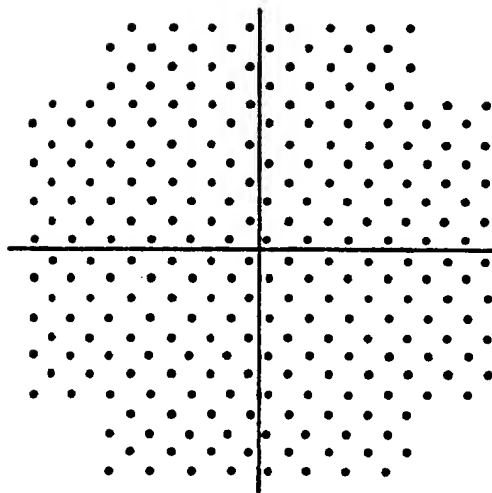


FIG. 2d

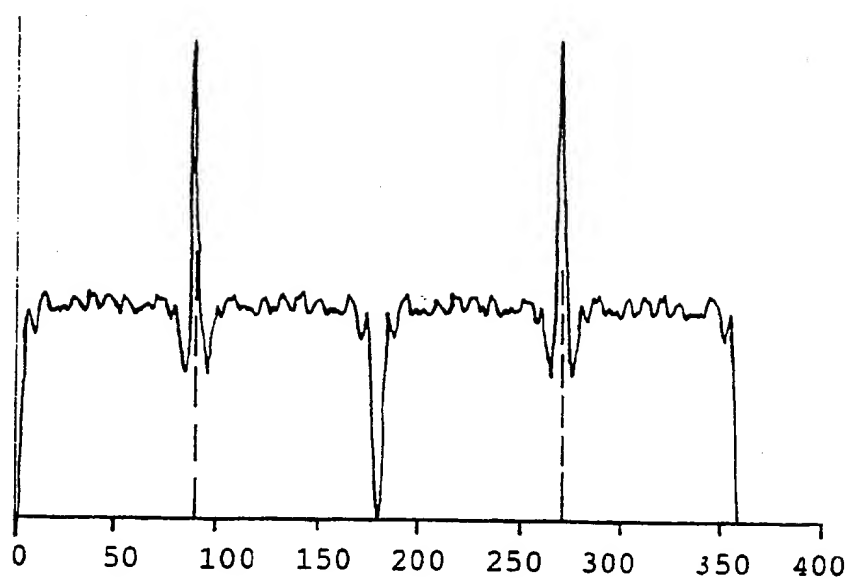


FIG. 3



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EUROPEAN SEARCH REPORT

Application Number

EP 89 48 0107

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	EP-A-0 238 822 (NEC) * Abstract; figures 1,2 * ---	1,2	H 04 L 27/34 H 04 J 3/06
A	ELECTRONICS, vol. 39, no. 22, 31st October 1966, pages 91-94; M. POPPE: "Double phase-shift keying speeds data over voice channels" * Page 91, column 2, paragraph 3 - page 92, column 1, paragraph 2; fig. at foot of page 92 * ----	1,2	
A	PATENT ABSTRACTS OF JAPAN, vol. 12, no. 291 (E-644), 9th August 1988; & JP-A-63 067 851 (FUJITSU) * Abstract * -----	1,2	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			H 04 L H 04 B H 04 J
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 12-03-1990	Examiner SCRIVEN P.
CATEGORY OF CITED DOCUMENTS			
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